DESIGN OF A REINFORCED CONCRETE ARCH

J. A. MEGAHY

ARMOUR INSTITUTE OF TECHNOLOGY

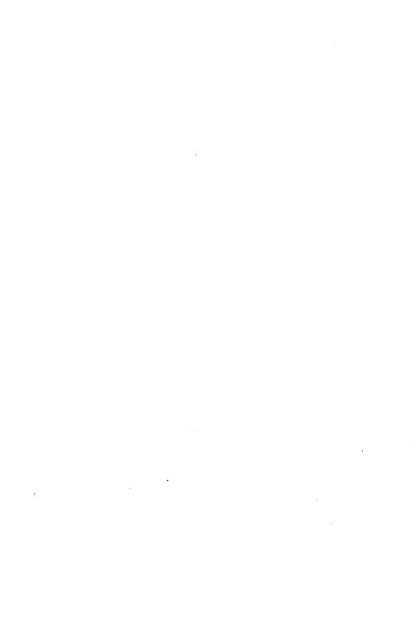
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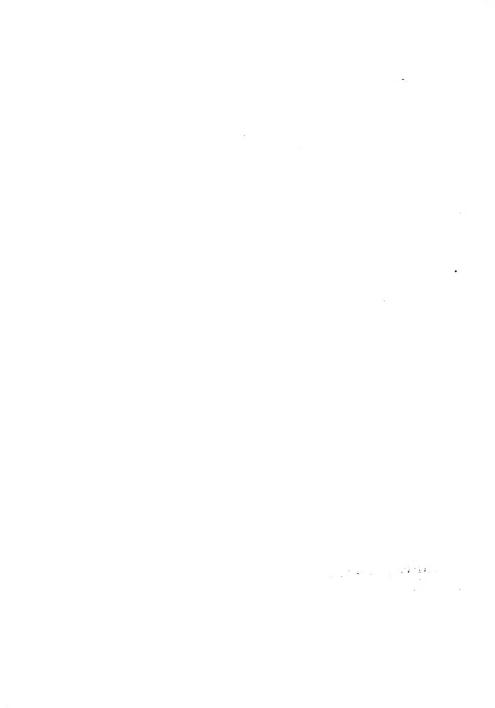


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AT 151 Megahy, James A. Design of a reinforced concrete arch







Design of a Reinforced Concrete Arch

A THESIS

.... PRESENTED BY ...,

James: A. Negaty

PRESIDENT AND FACULTY

OF THE

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

Bachelor of Science in Civil Engineering

Having Completed the Prescribed Course of Study in Civil

ENGINEERING

APRIL 1ST 1909

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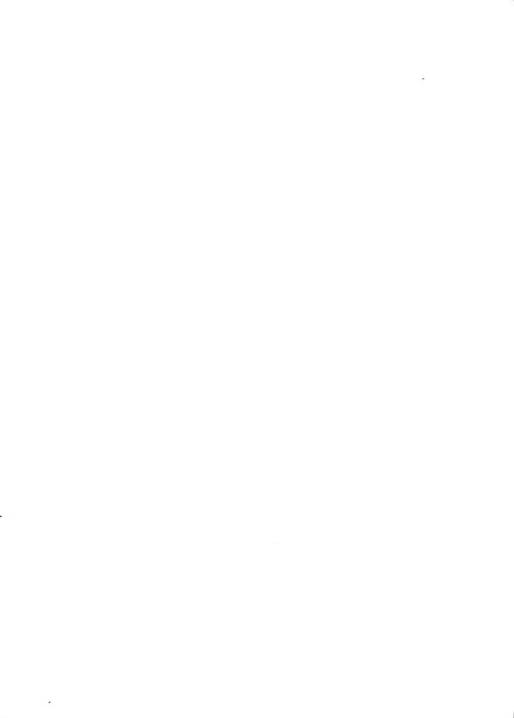
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" THESIS."

" THE DESIGN OF A REINFORCED CONCRETE ARCH

The arch is to have a total width of 38ft., 22 ft. for roadway and two 8 fcct cement sidewalks. The live load is to be 10° lbs

per sq. ft. and provision is to be made for street car traffic.

LOA DING: - The car track occupies a width of 16 2/3 ft. and the live

load per linear foot of track 1800 p er sq.ft. Remaining floor surface 160 lbs per sq.ft. including sidewalks.

DEAD LOAD: - Concrete 150 lbs per cuefte
Earth fill 120 " " " "
Pavement 12"deep 150 lbs per cuefte
Car track 25 lbs per sq.ft.

LIVE LOAD: - 1800 los per linear ft. of bridge over 16 2/3 width 100 "sq.ft. for remainder of floor surfac e.

" METHOD OF DESIGN."

deflection polygons from Prof. Burr's "Stresses in Bridge and Roof Trusses." The methos of finding the summations by tabulation is due to Mr. Thacher. In the design of an arch, the method consists in finding the true equilibrium polygon for any system of loading and its true position in the arch ring. The conditions which, when fulfilled, give the results are (I) that the tangents to the neutral line of the ring at the springing are fixed in direction (2) that the span is invariable; and (3) that the vertical deflection of one springing line with respect to the other is zero.

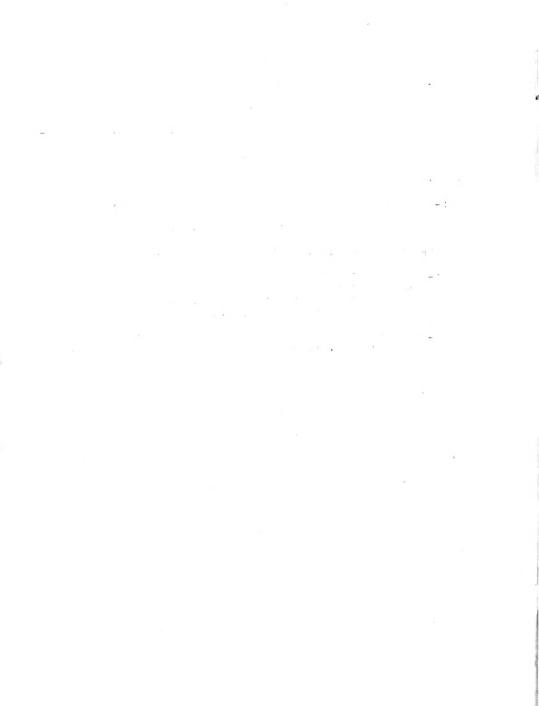
The method used is that of Prof. Cain, with the construction of the

Expressed mathematically, these conditions are:

$$\sum \frac{Ms}{EI} = 0;$$

$$\sum \frac{Mys}{EI} = 0;$$

$$\sum \frac{mxs}{E} = 0;$$



in which (s) is the length of a small division of segment of the ring measured on the neutral line and (y) and (x) are, respectively, the ordinate and absissa of the center of (s) with the origin at one springing; For a reinforced concrete ring these equations of condition take the form

$$\sum \frac{M_s}{E_c(I_{c+e}I_s)} = 0; \sum \frac{My_s}{E_c(I_{c+e}I_s)} = 0; \text{ and } \sum \frac{Mx_s}{E_c(I_{c+e}I_s)} = 0;$$

Let H = horizontal thrust, which is constant throughout the ring for any given loading.

the intercept of the ordinate between the neutral axis and the line of pressure.

M=Ht, and e=Ee/Eq practically constant throughout then if we make s: (textex) constant by construction $\frac{Hs}{c(\text{Ic+eIs})}$ may be placed outside of the sign of summation and we have , $\sum t=0$, $\sum ty=0$, and $\sum tx=0$

 $I_c \div I_S$ is constant throughout the ring, therefore making S: I_c constant fulfills the condition.

Since I_{c} b h^3 :12, where (b) is the thickness of the slice of the ring considered, usually 12 inches and (h) is the radial depth of the ring we may construct s: h^3 constant.

The rise (1) was made 1/3 of the span or 10 feet.

The radius of the center line= $(R) = \frac{r^2 + (L^2 + 4)}{2r}$ where L is the length of the span.

The ring was propotioned and subdivided into 18 segments (s) so as to make single constant. The spacing is shown in table I. The loads are then computed by table II, the live load is placed over the half span to give bending moments, maximum or nearly maximum.

. Cara III and Area and Area , Ku

TEMPERATURE STRESSES.

Sin ce the top of the arch is covered and the underside cannot be reached by the sun's rays, the changes in temperature do not affect the arch in most cases, an appreciable amount. If temperature stress are considered, the thrusts and bend ing moments on any section can

be computed from the formula $H = \frac{\text{Eelre}}{\sum y^2 - m \sum y} \frac{\text{Ic-els}}{S}$ where $\frac{1}{\sum y^2 - m \sum y} \frac{1}{S}$ l = the span of the neutral surface. c = the change of temperature of the ring in degrees Farh.

r = rate of expansion per degree Farh. $r = (\Sigma_0^n y) \div n$

n = number of divisions of the ring, "s" ; The thrust on any section will be resultant of H perpendicular to

that section, and the bending moment will be $, M=H \times (y-m)$. Table IV gives the thrust and bending moments of several points of the ring for a change in temperature of 42° Farh.

Table V gives the final stresses per sq.in. in the ring at the crit-

ical points also the assured and adjusted thicknesses. After finding the final stresses, the intensities of the stresses in all parts of the concrete and of the steel reinforcement are computed from Mr. Thacher's formulas $f_{e} = \frac{T}{Actea} + \frac{bhM}{IcteIs}$ and $f_{e} = \frac{eT}{Actea} + \frac{behM}{IcteIs}$ in which

fc=intensity of stresses in the concrete $f_s=$ " " " steel-

T = thrust on section line I wide,, in lbs. Ac=area of section of concrete I wide, square inches. $e = E_s \div E_c$ where E_s modulus of elasticity of steel and

 $e=E_s\div E_c$ where $E_{\overline{s}}$ modulus of elasticity of steel and $E_{c}=$ " " concrete.

a marea of steel per inch width $A_s \div b$, square inches • h = depth of concrete in inches• "

M = bending roment on section 1 wide ft lbs.

Icamoment t of inertia of concrete, Ac, about the neutral axis of the combination.

Is=momentat of inertia of steel, (a), about the neutral axis

of the combination.
b=distance from center to center of steel members, in the direction of the width of the arch, inches

- -

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1

10-

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h = depth of steel in inches.

The computation of the stresses in the steel and concrete are found

ing of surfaces.

in table VI . The total height of the spandrel wall will be 12 ft. at the springing . Supposing the earth fill to have an angle of repose of 26° 34' or a natural slope of 1 on 2, then the horizontal thrust

$$P = \frac{wx^{2}}{2} \left(\frac{1 - \sin \phi}{1 + \sin \phi} \right) \qquad w = 120 \text{ lbs, cuft.}$$

$$\chi = 12'$$

$$\phi = 26' 34'$$

$$P = \frac{120 \times 144}{2} \times \left(\frac{1 - 447}{1 + 447} \right) = 3301.25 \text{ lbs.}$$

Bending moment at junction of spandrel wall and top of arch.

= 3301.25 ×
$$\frac{y}{3}$$
 = 13205 ft lbs.
M= $\frac{w\ell^2}{8}$ w= $\frac{8M}{\ell^2}$ = $\frac{13205 \times 8}{144 \times 12}$ = 61.1bs, sq.in.

This stress is within the allowable limits and the wall will be 10 " thick at top and 13 " at bottom.

SPECIFICATIONS.

and, are either monolithic or of reinforced concrete. They embrace providing all materials and labor to construct and complete the work making and placing of forms, bending and placing of steel, mixing and placing of concrete, removal of forms, removing rubbish and finish-

These consists of the portion of the structure indicated on the plans

FORMS: - The forms should be of such a character that after they are removed all surfaces will be plain and level and have the proper elevations called for . Wherever a surface finish is to be used, rough lumber can be used on that side. The size, thickness, and quality

of the lumber being left to the discretion of the contractor. forms should not be removed until the concrete has become hard



enough to sustain its own weight and the probable weight liable to be superimposed. Shores should be left in place at least four weeks. Before concreting, all forms should be cleaned of saw-dust, blocks shavings, dirt and dust, holes patched with tin, oiled and sprink-led.

CONCRETE: - The concrete is required to be mixed by volume; 1-3-6 being required for footings and foundations and 1-2-4 for structural members 1-2 mortar for finish and this should never be less tham 1/2 inch in thickness. Water enough to make a pasty mixture is required.

(Note - By 1-3-6 is meant 1 part cement, 3 parts sand, 6 parts by volume of broken stone or gravel.

CEMENT: - All cement used shall be Portland cement and shall be inspected either at the place of manufacture or on the work. In order to allow ample time for inspecting and testing, the cement shall be stored in a suitable weather-tight building, having the floor properly blocked or raised from the ground. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment. Every facility shall be provided by the contractor and a period of at least 12 days allowed for the inspection and necessary tests. Cement shall be delivered in suit able packages with the brand and name of the manufacturer plainly marked thereon.

A bag of cement shall contain 94 lbs of cement net. Each barrel of Portland cement shall 4 bags of the above net weight. Cement failing to meet the seven days requirements may be held awaiting the results of the 28 day tests before rejection. All tests shall be made in accordance with the methods proposed by the committee on Uniform Tests of Cement of the American Society of Civil Engineers,



presented to the society January 21, 1903 and amended Jan. 20 1904, with all subsequent amendments thereto. The acceptance or rejection shall be based on the following requirements: Portland Cement:

Definition: This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly propotioned argillaceous calcareous materials and to which no addition greater than 3% has been made subsequent to calcination.

SPECIFIC GRAVITY.

The specific gravity of the cement thouroughly dried at 100° C shall be not less than $3 \cdot 10 \cdot$

FINENESS.

It shall leave by weight a residue of not more than 8 % on the No- 100, and not more than 25% on the No- 200 seive-

TIME OF SETTING.

It shall develop initial set in not less than 30 minutes, but must develop hard set in not less than one hour, nor more than 10 hours.

TENSILE STRENGTH.

The minimum requirements for tensile strength for briquettes 1 square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

One part cement, three parts sand.

7 days (i day in moist air, 6 days in water) -----150 - 200 lbs. 28 days (1 day in moist air, 27 days in water) 200 - 300 lbs.



CONSTANCY OF VOLUME.

Pats of neat cement about 3 diameter, 1/2 thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours. (a) a pat is then kept in air at normal temperature and observed at intervals for at least 28 days. (b) Another pat is kept in water maintained as near 70°F. as practicable and observed at intervals for at least 28 days. (c) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours. These pats, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegrating.

SULPHURIC ACID AND MAGNESIA.

The cement shall not contain more than 1.75% of anhydrons sulphuric acid (S on the more than 4% of magnesia (M S O).

SAMPLING.

The sample shall be a fair average of the contents of the package; it is recommended that, where these conditions permit, one barrel in every 10 be sampled. All samples shall be passed through a seive having 20 meshes per linear inch in order to break up lumps and remove foreign matter; this is also a very effective method of mixing them together in order to obtain an average. For determining the characteristics of a shipment of cement, the individual sample may be mixed and the average tested; where time will permit, however, it is recommended that they be tested separately.

METHOD OF SAMPLING.

Cement in barrels should be sampled through a hole made in the center of one of the staves, midway between the heads, or in the head by means of an auger or a sampling iron similar to that used by



sugar inspectors. If in bags, it should be taken from surface to center.

SAND.

All sand shall be clean sharp sand, not having any excessive amount of foreign material in the form of loam or clay; 10 % can be allowed.

BROKEN STONE.

Stone should pass a 3/4 in. ring for small work, 1 1/2 for large work; screenings, if clean, are permitted. All stone should be free from dirt which mught keep the cement from adhering to the stone.

Sandstone/ limestone, granite, traprock or other stone can be used.

GRAVEL.

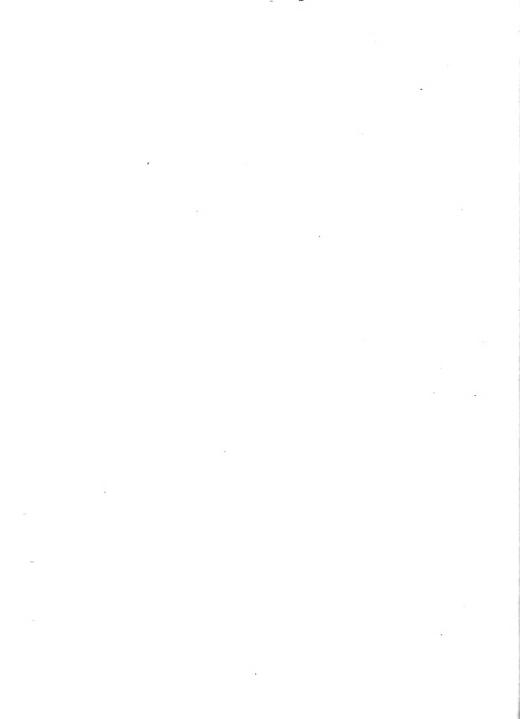
Gravel should be not larger than that passing a 3/4 ring and shall contain no sand unless the portion of sand in the mixture used is reduced. It shall also be free from clay, loam and other extraneous material.

MIXING AND PLACING.

The mixing can either be done by hand, the cement, sand and stone being placed on a water tight mixing board, or mixed in a batch mixer The propotion of water determined according to the nature of the materials being mixed; to give same a good, pasty, well mixed consistency. The concrete shall be handled quickly and brought to the points of placing by hoists, derricks, concrete buggies or wheel-barrows, proper runs being supplied so that the steel may not be displaced. No concrete that has begun to show signs of set shall be used.

WATERPROOF ING.

The top of the arch and the sides of the spandrel walls shall be



w aterproofed with 1/2 coating of cement mortar consisting of 1 part cement to two parts of sand and average shall be provided at the haunches by means of an unglazed clay pipe reaching diagonally from the center of the space over the abutment to the soffits of the archithrough which it projects about an inch. The surface of the abutment is dished toward the upper end of the pipe, which is covered with wire netting to exclude coarse material and a bed of broken stone is laid over all to receive the earth fill.

SPANDREL WALL AND PARAPET WALLS.

The spandrel wall shall be made of 1-2-4 concrete and shall be connected to the cornice by parapet walls by means of an anchor bolt 1'' square and five ft• long as shown in plans•

The cornice is to be of 1-2-4 concrete and made in seven foot sections and laid in sections like cut stone.

The parapet wall shall consist of concrete posts 8 x 12 of 1-2-4 concrete and shall be moulded on the bolt from the spandrel wall as shown in plans. A hand rail of wrought iron pipe 2 internal diameter shall be provided and moulded into the parapet wall. The hand rail shall enter the smallest dimension of the posts, and to a depth not less than four inches. All joints between the arch ring, spandrel walls, cornice, and parapet walls, shall be filled with cement mortar of a consistency of 1-2.

RE INFORCEMENT .

All steel shall be medium steel, having an ultimate tensile strength of from 6 0,000 to 68,000 lbs per sq.in. and an elastic limit of not less than 1/2 the ultimate strength and should elongate not less than 22% in 8 and bend cold 180 around a diameter equal to the



thickness of the piece tested without fracture on the outside of bend.

The I beams used shall be riveted at the abutments to a 5x5x1/2 angle iron extending along the entire length of the abutment and embedded therein. All reinforcement shall be not less than 3 infrom the exposed surface of the concrete.

Signed James A. Megaky april 1st o 4" 1 · 4 · * 1

THBLE I.

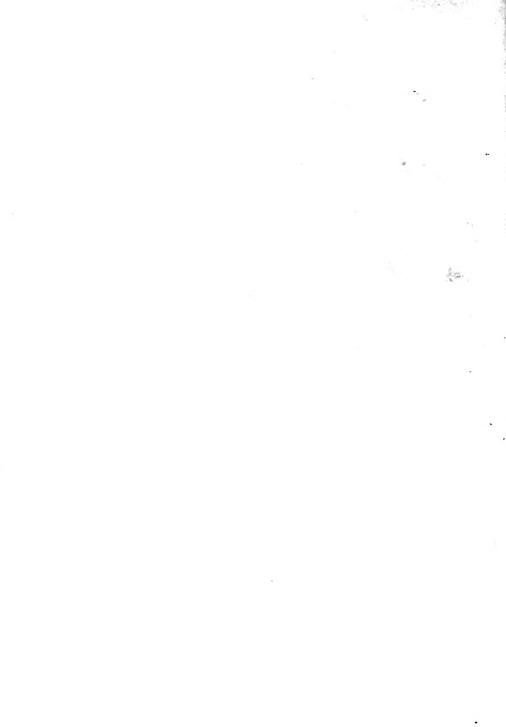
	F	irst Tri	al al	2rd Trial	3rd Trial	1	
Point	h	£13	5	5	5 4	-	Correct
	2.50	15-62	11. 2.5	10.46	10.75	ĺ	
2	2.37	13.31	9.58	8.91	9.0.5	}	
3	2.11	9.39	6.76	6.29	6.38	}	
4	1.82	6.02	4.33	4 03	1.09		
5	1.70	4.91	3.53	3.28	3.38		
6	1.62	4.25	3.06	2.84	2 89		
. 7	1.58	3.94	2.83	2.63	2.67]	
8	1.55	3.72	2.67	2.49	2.52		
9	1.52	3.5/	2.52	2.35	2.38]	

TABLE.II.

P: 40	Length	Ring 150.	LBS ou ft.	Fill 120 Depth ft.	LBS.cu. +1.	Pavement 12" deep	Width of	Total, Dead,	LiveLous		Summari
1011113	ft.	Depth ft.	LB5.	Depth ft.	LBS.	150LBS.	25LBS	Load LBS.	LBS.	LB5.	LBS.
1	10.75	2.50	9909	10.12	10486	1110	231	21736		21736	21736
2	9.05	2.37	3146	6.75	680:5	991	206	11148		111.48	32884
3	6.38	2.11	2009	4.87	3525	705	146	6385		6385	39269
4	4.09	1.82	11.41	4.00	1849	450	93	3533		3533	42802
5	3.38	1.70	867	3 70	14.62	390	- 81	2800		2800	45602
6	2.59	1.62	706	3.60	11.78	330	68	2282		2282	47884
7	2.67	1.58	632	3.45	1035	300	62	2029		2029	49913
8	2.52	1.55	582	3.35	904	270	56	1812		1812	51725
9	2.38	1.52	537	3 10	803	255	.5-3	1650		1650	53375
Total			19531		28047	4801	976	53375		53375	
10								1650	229	1874	1879
1/								1812	235	2047	3426
12								2029	270	2294	6225
13								2283	297	2574	8804
14								2800	35/	3151	11955
15								3533			15893
16								6385	634		22412
17								11148			34949
18								21736		22736	
Total	(- (53375		57675	
Grand	Total							106750		111060 00 LBS.	

TABLEIII.

Point	2-4		yilibriui Ixaon	ריב	Tria	ngles	Ordina?	tes for	Ordinate De fi	antinn	True	CI MIMORIA		
10111	Ordinates Arch	Ordinates	Laver	Moments	Crdinates	Moments	(mpm)		arch	E9 / P.IV.	Col8x 1/2	Dateman C 194	Col+3x4	Thrusts
V	0.00	0.00					-(13.46)	(-8)			-(8 00)	3	-33:51	166875
/	2.33	4.87	1.62	22.49	.77	3.61	-869	-5-63	-11.26	-17.45	-557	+.06	tc	90373
2	4.75	10.37	13.50	139.99	2.26	30.64	-3./5-	- 2.12	-15.50	-23 68	-2.02	T ./C	+8370	80250
3	7.75			273 2/			36	1					+ . 6.74	84750
4	8.75	14-62	25.50	372.81	4.28		t.1.13							
5	9.25	15.33	28.91	443.19	4.85	141.20	+1.82	+1.37	-11.52	-19.39	+1.16	21	-17577	83425
6	9-63	15:75	31.87	501.95	535	170 55	t.2.21	+1.63	-8.40	-15-16	+1.41	22	-184.4	53600
7	9.88	15.91		T			+2 43					32	-26784	
8	10.00	16.12	36.87	594.34	617	228 28	+ 2.50	t-2.00	52	-5-31	+1-60	40	-33480	
9	10.08	16.16	39.08	631.53	6.56	256.36	+2.68	+2.04	00.00	00.00	± 1-72	32	- 33480	83800
10	10.08	16.08	41.25	663.30	6.93	285.86	+2:63	+2.04			+ 1.70	34	-28458	
//	10.00	16.00	43.50	696.00	7.30	3/7.55	+ 2.62	+2.00			\$1.68	32	-20784	
12	9.88	15.75	45.87	722.45	7.70	303.27	+2.28	+1.87			+ 1 37	- 30	3.732	83437
13	9.63	15.50	48,50	7.5% 7.5	8.14	394.79	+2.04	+1.63			+1.30	33	-27621	83625
14	9.25						+1.61						-25458	
15	8.75						+ .90						-25110	-
16	7.75	12.83					5-/				32		-5752	
17	4.75	9.87					7.38						-7348	
18	2.33	4.66					-8.76						+ 837	
11'	0.00	0.00	17.100	52.07	14 11	10216	713.39)						-49787	
	1.14 84			9688.65	121.32	5813.87	(12.37)	10.09			16.0	9-7	_T/3/3	7./10/



	7	ABL	E:IV						
"H" due to temperature = 796.32/bs									
Point	Moment	Thrust	Total Mement	Thrust					
_'V"			53568	100875					
	1722.97		97-14	90375					
4	503.00		13058	84375					
6	1080-42	2/6	19534	83500					
10	1150.00		29508	83400					
12	1319.50	3	31451	8.3437					
15	503.00	0,	25613	84375					
18	4722.97		5539	89250					
"y'"			44383	99187					

	~	TABL	E.V.	
PC int	7 to 14	Mi for I'multo	7/11/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2/2	Tueriers
"V"	8-206	1161		333
	7.531	812	2:50	3-16
4	7737	1013	1.82	2.29
6	1766	162.7	1:62	2.04
10	675C	2459	1.52	1.42
12	3252	2630	1.08	1.99
15	70.31	2134	1.62	2.21
18	7437	4-63	2.50	3.16
"V"	1265	4115		3 33
	1			1

TABLE III.

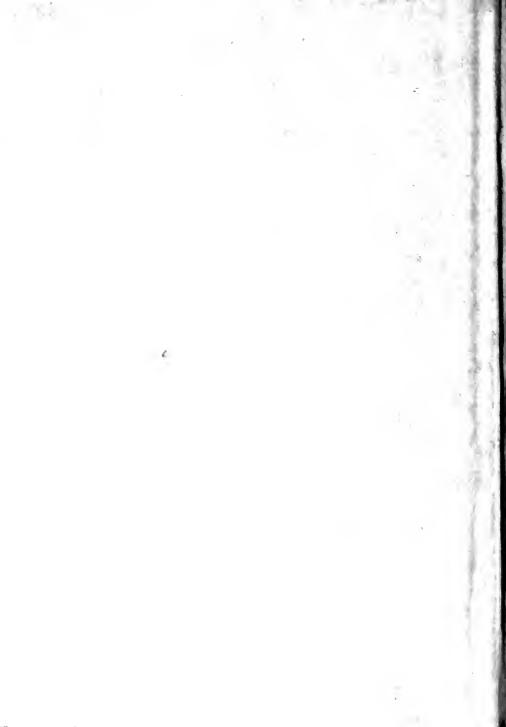
1 / 1 lage Line Balls o							
Es	= 29,000	000	12" 31/2 lb. I bean	z spaciny = 30"c-c.			
Ec.	= 19333	33	$a = \frac{9.26}{30} = .308$	· ·			
e =	15		ea = 4.62				
fc =	Actea	+ 6 R M IcteI	Is = 215.8 - 7.19	fs = ET + Geh M Actea - IcteIs			
				compression = 550 /65.0"			
4	llowable	unit s	stress in Concrete =	tension = 65/bs. 0"			
Point	area of Section	$I_C = \frac{F_1 J}{I_2}$	fc ./65. 0"	fs 165,0"			
,	37.92	4543	$f_{c} = \begin{bmatrix} 753/\\ 37.92 + 462 \end{bmatrix} + \frac{6x8/2x37.92}{4543 + 107.85}$ $= (176 \pm 39) = +225$ $+137$	fs=187531 27.92+4.62 4872×12 4543+10785			
'			= (176 ± 39) = + 225 + 137	= (177 ± 12) 15=+2825 +2475			
			fc= 7031 + 6 x 1088 x 27.43	f5=219+6486 ×12 ×15			
4	27.48	1729	= 2/9± 97=+3/6 +/22	=(219 ± 42) 15=+3915 +2655			
	24.40		fc = \frac{6066}{2448+4.62} \frac{162648}{1222.5+10718} = (234 \frac{1}{2}) = 1257	+5= 339+6×1628×12 ×15			
0	24.40	1222.3	=(23/1/8)=+257	=(23918.8)15=+3720			
			$f_{c} = \begin{cases} \frac{6950}{23+4.62} + \frac{6 \times 2459 \times 23}{1014 + 107.75} \\ = 251 + 296 = +549 \\ -47 \end{cases}$	f5 251 + 19170412 ×15			
10	23.	1014	= 25/ 1298 = +549 - 47	=(2517157)15=76120+1410			
		1	fc= 6958 + 6×2620×23.88 23.68+4.62 1134.8+107.85	fs= 243 + 15720 x12 x15			
12	23.88	//34.8	= 243 ± 303 = 1546	=(243 ± 151)15=+5916 +1380			
			fe= 7031 + 6x2134x27.48 27.48+462 1729+107.85	for 219± 6x2134 x12 x15			
15	27.48	1729	= 219 ± 191 = +410 +28	=(219 I 83) 15 = +4530 +2040			
			fc = 7437 + 6x463x37.92 37.92 +462 4543+107.85	fo= 174 ± 2778×12 ×15			
18	37.92	4543	= 174 ± 22 = +196 +152	=(17417)15=+2715			
V'	10	5333.33	fe = \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \	65- 188 + 26784 x 12 x 15			
1	40	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	= 188 ± 196 = +384	=(188+59)15=+3705 -1935			



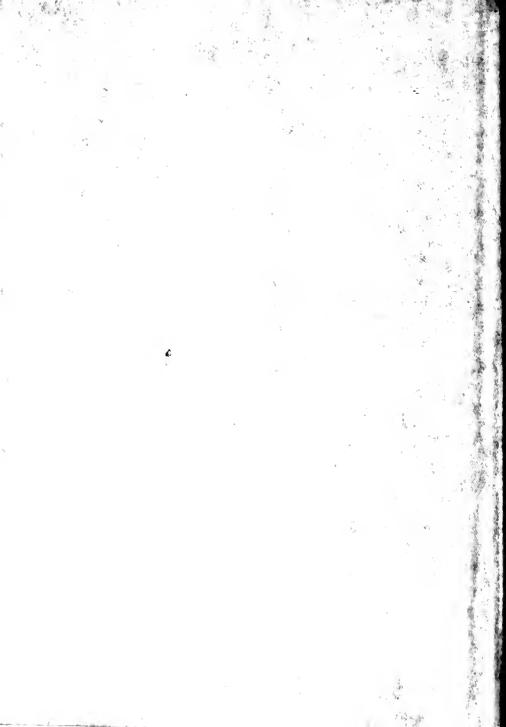
6.17 228.28 +2 50 + 6.56 256.36 + 2.68 + 285.86 t 2 7.30 962 76 - 8: 76 - 56: 12.71 (13.39) (-8.00 121.32 5813.87











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